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# TECHNICAL MEMORANDUM

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| **To:** | U.S. Environmental Protection Agency, Region 6<br>Texas Commission on Environmental Quality | **Date:** | September 26, 2011 |
| **From:** | C. Kirk Ziegler, Anchor QEA, LLC<br>Patrick Bayou Joint Defense Group | **Project:** | 040284-01 |
| **Cc:** | Files | | |
| **Re:** | Response to EPA/TCEQ Comments on *Draft Sediment Transport Modeling Report, Patrick Bayou,* June 2009 | | |

Comments on the Draft Sediment Transport Modeling Report, Patrick Bayou (June 2009) were received from U.S. Environmental Protection Agency (EPA), Region 6 and the Texas Commission on Environmental Quality (TCEQ) during August 2009. This memorandum presents responses to the EPA and TCEQ comments.

## RESPONSES TO EPA COMMENTS

Comment 1: Sec 1.1, pg 3, 1st line: Quantify "not significantly stratified". Is this true over an entire lunar month?

*Response: The text was modified such that "not significantly stratified" is quantified. Yes, lack of significant stratification exists over the spring-neap tidal cycle.*

Comment 2: Sec. 2.2.2, pg 12, 3rd para, 5th sentence: What type of averaging of the measured rainfall was performed, i.e., linear, spatially weighted?

*Response: Arithmetic averaging of the rainfall data was used. Text was modified to note this.*

Comment 3: Sec. 2.3.4, pg 21, 3rd para: Statistics (e.g., average error, relative error, average absolute error, root mean square error, relative absolute error) that quantify how well the calibrated model matches the data should be added.

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*Response: Table 2-4 was added, which lists the average absolute and RMS errors.*

Comment 4: Sec. 2.4.2, pg 28, 2nd para, 1st line: Change 'Table 2-3' to 'Table 2-5'.

*Response: The text was modified as requested.*

Comment 5: Sec. 2.4.3, pg 32, 2nd para, 3rd sentence: A 6-cm thick top layer is too thick to determine the gradient in bed properties, e.g., bulk density and critical shear stress for resuspension that typically occurs in cohesive sediment beds. Such a thick layer should not be used in Sedflume tests. A sensitivity test should be performed to determine the impact of using such a thick surface layer in the model.

*Response: Use of a 6-cm thick top layer was necessary due to the procedure used in the Sedflume tests. The first shear stress series used during the Sedflume tests was applied to the top 6 cm of the sediment cores. Thus, the erosion rate parameters obtained from the Sedflume tests represent the average, or composite, values for the top 6 cm. It is not possible to determine erosion rate parameters at higher vertical resolution due to limitations in the Sedflume tests.*

Comment 6: Sec. 2.4.3, pg 32, 3rd para, 5th sentence: Change 'of the all cores' to 'of all the cores'.

*Response: The text was modified as requested.*

Comment 7: Sec. 2.4.3, pg 32, 3rd para, 8th sentence: I do not see PB040 on any of the figures.

*Response: The location of station PB042 was added to the appropriate figures.*

Comment 8: Sec. 2.4.3, pg 33, last para, 1st sentence: What assumption is referred to in this sentence?

*Response: The text was modified to clarify this sentence.*

<u>Comment 9</u>: Sec. 2.4.4, pg 35, last para, 7th sentence: Details of the global mass balance should be included in an appendix.

*<u>Response:</u> Details of the mass balance analysis were added to the main text, see pages 37-39.*

<u>Comment 10</u>: Sec. 2.4.4, pg 36, 1st para, 1st sentence: How were the approximate values of 40%, 28%, and 100% determined? It states that these were first-approximation estimates, but no description of the method used to come up with these approximate values is given.

*<u>Response:</u> These assumptions were based on professional judgment and past experience form sediment transport modeling studies on other sites (this text added on page 39).*

<u>Comment 11</u>: Sec. 2.4.5, pg 38, 2nd para, 20th line: Provide an explanation why 'peak TSS concentrations would be expected to occur at station PB012 during more intense storms'.

*<u>Response:</u> This sentence was deleted.*

<u>Comment 12</u>: Sec. 2.4.5, pg 39, 2nd para, last line: Change 'Table 2-5' to 'Table 2-7'.

*<u>Response:</u> The text was modified as requested.*

<u>Comment 13</u>: Sec. 2.4.5, pg 40, para below Table 2-7: I think the results in the area located near station PB036 are affected by the coarse grid density in this area. The bayou in this area appears to be represented by only two lateral grid cells. Sensitivity tests using a denser grid should be performed to investigate this.

*<u>Response:</u> Sensitivity of the model to grid resolution was evaluated, see Sections 3.2.2 and 3.3.2 for discussions of this analysis.*

<u>Comment 14</u>: Sec. 2.4.6, pg 43, 1st sentence: Add "on" between "based" and "sediment".

*<u>Response:</u> The text was modified as requested.*

<u>Comment 15</u>: Sec. 2.4.6, pg 43, 1st para below Table 2-8: Change 'Table 2-5' to 'Table 2-8' in the first sentence. The analysis of the vertical concentration profiles for the listed chemicals mentioned in the last sentence should be presented in an appendix.

*<u>Response:</u> The text was modified as requested. A reference that contains the analysis of the vertical concentration profiles was added to the text.*

<u>Comment 16</u>: Sec. 2.4.6, pg 43, last para: The relatively high NSR predicted by the model at PB003 is most likely an artifact of the coarse grid used in the confluence area. As mentioned in this paragraph, there are complex interactions between the bayou and the HSC in this area, and the current grid is probably too coarse to accuracy represent the physics of this interaction. Sensitivity tests using a denser grid should be performed to investigate this. Also, discuss the implications/limitations of having only one Sedflume core in the wide confluence area on the modeling results.

*<u>Response:</u> Sensitivity of the model to grid resolution was evaluated, see Sections 3.2.2 and 3.3.2 for discussions of this analysis. There are no significant limitations or implications to the modeling results due to having only one Sedflume core in this area because spatially constant erosion rate parameters, in the horizontal plane, were used in the model.*

<u>Comment 17</u>: Sec. 2.4.6, pg 45, 1st para, last sentence: The data that show the exponential decreases in the concentrations of Hg, PCBs and PAHs should be added to Figs. 2-33 and 2-34.

*<u>Response:</u> The model predictions are not directly comparable to the chemical concentration data and it is unclear how that data could be added to these figures.*

<u>Comment 18</u>: Sec. 2.4.6, pg 45, 2nd para: The grid is also coarse in proximity to PB057, and this might be the cause of the inconsistency between model results and the non-interpretable $^{210}$Pb vertical profile.

*<u>Response:</u> Generally, increasing the resolution of the numerical grid did not significantly change model predictions. Thus, grid resolution does not appear to be the primary cause of the inconsistency noted in the comment.*

Comment 19: Sec. 2.4.6, pg 45, 3rd para: The conclusion stated regarding the validation results is valid at three of the five locations where data were available for comparison, but not at the other two locations. The existing model's limitation at the two locations should be mentioned in this paragraph.

*Response: Additional text was included on pages 47 to 49 that discusses model limitations at those two locations.*

Comment 20: Sec. 2.4.6, Fig. 2-35: What do the solid circles in this figure represent?

*Response: The text was modified to include an explanation of the solid circles.*

Comment 21: Sec. 3.1, pg 47, 3rd para, 2nd sentence: How does the assumed critical shear stress of 0.1 Pa compared with the critical shear stress determined from Sedflume tests in proximity to the seven marker-horizon locations?

*Response: Additional discussion was added to the text to address this comment.*

Comment 22: Sec. 3.2.1, pg 50, 1st para, 2nd sentence: The maximum net erosion of 7.6 cm shown in Fig. 3-6 is once again possibly the result of the coarse grid in the confluence area and the single Sedflume core in this area. The recommended sensitivity tests should investigate this as well.

*Response: Sensitivity of the model to grid resolution was evaluated, see Sections 3.2.2 and 3.3.2 for discussions of this analysis.*

Comment 23: Sec. 3.2.2, pg 51, 4th para: More discussion is needed on the results presented in Figs. 3-8 through 3-13. The previous comment also applies to the results shown in Fig. 3-9, in particular the cell in which 33 cm of erosion is predicted for the upper-bound erosion rate parameters.

*Response: Additional discussion was added to Section 3.2.2.*

Comment 24: Fig. 3-14: The upper plot shows that the normalized net erosion area for both the lower- and upper-bound erosion rate parameters are less than that for the base case. Explain this result as the reason for this result is not readily apparent.

*Response: Discussion was added to the text to explain this result.*

Comment 25: Sec. 3.3.2, pg 56, 1st para: Why are NSR values plotted in this figure laterally averaged? This mode of presentation is fine, but it would be valuable to also show the results for each cell. The noted increase in the NSR within 0.2 miles of the confluence might again be a result of the coarse grid in this area.

*Response: Even though variability in NSR exists in the lateral direction, examining the spatial variation in laterally-averaged NSR is informative for understanding large-scale variations in sedimentation patterns and for comparing results of the uncertainty simulations.*

Comment 26: Sec. 3.3.2, pg 56, 2nd para, last two sentences: Explain why "the parameter combinations for uncertainty simulations 4 and 5 produce results that correspond to realistic lower- and upper-bound parameter sets".

*Response: Discussion was added to the text to address this comment.*

Comment 27: Sec. 3.3.2, pg 57 2nd para, last sentence: Change 'mode' to 'model'.

*Response: The text was modified as requested.*

Comment 28: Sec. 3.3.2, pg 57, 3rd para, 2nd sentence: The range from 35% to 94% is fairly wide, but it is good to have this uncertainty quantified to this degree.

*Response: No response is needed to this statement.*

Comment 29: Sec. 4.1, pg 58, 3rd para, 1st bullet: Insert 'be' between 'may' and 'used'.

*Response: The text was modified as requested.*

Comment 30: Sec. 4.1, 4th para: By what recognized estuarine parameter would the Patrick Bayou be classified as a well-mixed estuary. Also, change '10 to20 ppt' to '10 to 20 ppt' in the 1st sentence.

*Response: The statement that the bayou is a well-mixed estuary was deleted because it did not provide any significant information. The text was modified as requested.*

Comment 31: Sec. 4.3, pg 63, 1st bullet, last sentence: Is the 10 cm the maximum scour depth or the maximum net scour depth?

*Response: This prediction corresponds to the maximum net scour depth.*

Comment 32: Sec. 4.3, pg 63, 2nd bullet: How was it determined that "sediment originating in the HSC is transported no more than 0.2 miles upstream of the mouth of the bayou".

*Response: This statement was deleted.*

## RESPONSES TO TCEQ COMMENTS

### Section A: Technical Review Summary

Comment A.1: The purpose of the modeling described in the subject report is to establish a quantitative sediment transport model for Patrick Bayou. The results of the sediment transport model may be applicable to evaluations of a natural recovery remedy option in the forthcoming Feasibility Study.

*Response: The sediment transport model will be used to evaluate the effectiveness of a range of remedial alternatives, including the evaluation of natural recovery.*

Comment A.2: The subject report is concerned only with the quantitative sediment transport mechanics, modeling and potential consequences in Patrick Bayou. No contaminant fate is modeled.

*Response: This comment is an accurate statement. A sentence has been added to Section 1 Introduction noting that chemical fate and transport was not simulated in this study.*

Comment A.3: The sediment transport physical model comprises three (3) major elements: hydrology (Sec C), hydrodynamics (Sec D), and sediment transport (Sec's E, F, H and J).

*Response: This comment is an accurate statement.*

Comment A.4: The numerical modeling of the Patrick Bayou sediment system required the coupling of different models to simulate all the physical processes associated with the modeling objective (Item A.3).

*Response: This comment is an accurate statement.*

Comment A.5: The sediment transport model used Pb isotopy methodologies and data described in a separated report (Ziegler et al., 2009), whose review is also included herein (Sec H).

*Response: Net sedimentation rates at six locations in the bayou, based on a geochronology analysis of radioisotope cores, were used to calibrate the sediment transport model.*

Comment A.6: The subject modeling report does not incorporate major outfall discharges that occurred during the time period for which system modeling and calibration was performed. The TCEQ discusses these outfalls and the potential consequences to the modeling effort (Sec G, Appendix A).

*Response: The inflows from the three OxyChem outfalls have been incorporated into the hydrodynamic and sediment transport models.*

Comment A.7: The subject document does not address groundwater influxes to the bayou through the sediment bed. Some of the groundwater entering the bayou is known to be impacted. The TCEQ discusses some details and potential consequences associated with the groundwater influx as it relates to the sediment transport model (Sec I).

*<u>Response</u>: Groundwater inflow is not included in the hydrodynamic and sediment transport models because has a negligible effect on sediment transport processes in the bayou.*

<u>Comment A.8</u>: The subject report describes the mechanics of the attenuation process that was actually modeled (Sec J).

*<u>Response</u>: The sediment transport model was used to evaluate the rate of natural attenuation in surface-layer sediment due to mixing of sediment from external sources with bed sediments. Chemical fate and transport processes affecting natural attenuation in the bayou were not simulated.*

<u>Comment A.9</u>: The modeling effort does not incorporate contaminant fate of sediments associated with a natural recovery process. The TCEQ discusses some related points (Sec K).

*<u>Response</u>: Chemical fate and transport processes affecting natural attenuation in the bayou were not simulated.*

## Section B: Patrick Bayou Physical Model

<u>Comment B.1</u>: The bayou system physical model described in the subject report incorporates several physical processes which are coupled by successive numerical models and calculations.

*<u>Response</u>: The watershed model was used to predict freshwater inflow to Patrick Bayou due to runoff from the surrounding watershed during rain events. The hydrodynamic model was used to predict water surface elevation (water depth), current velocity and salinity in the bayou and HSC. The sediment transport model predicts suspended sediment concentration, deposition and erosion fluxes, and bed elevation change.*

<u>Comment B.2</u>: Patrick Bayou is considered to be an estuarine system (Sec 1.1, Subject Report). However, at low tide or during periods of wind-driven drawdown the intertidal areas can dry and the flow through Patrick Bayou is more channel-bound, resembling a fluvial system.

*Response: The bayou is composed of inter-tidal and sub-tidal areas, with the extent of the inter-tidal areas being affected by a combination of tidal and low-frequency storm fluctuations in the HSC-Galveston Bay system.*

Comment B.3: Three (3) major elements comprise the physical model: 1) system hydrology (Sec C), 2) system hydrodynamics (Sec D) and 3) system sediment transport (Sec's E, F, H and I).

*Response: This comment is an accurate statement.*

Comment B.4: The Patrick Bayou hydrology module (Sec C) is used to construct the Patrick Bayou watershed model that accounts for the various surface water discharges to the bayou.

*Response: Hydrologic and watershed information and data were used to develop, calibrate and apply the watershed model.*

Comment B.5: The Patrick Bayou hydrodynamic module (Sec D) is used to predict water levels, depths, discharges, velocities and bed shear stresses during a range of foreseeable flow events.

*Response: This comment is an accurate statement*

Comment B.6: The Patrick Bayou sediment transport module (Sec's E, F, H and I) is used to predict suspended sediment concentrations, sediment deposition rates, sediment erosion rates and bed elevation changes.

*Response: The sediment transport model predicts: 1) suspended sediment concentrations; 2) spatial and temporal changes in bed elevation; 3) gross erosion fluxes; 4) gross deposition fluxes; and 5) net erosion or deposition rates.*

## Section C: Patrick Bayou System Hydrology (Watershed) Module

Comment C.1: The subject report describes a standard method by which to calculate freshwater discharges from the bayou watershed to Patrick Bayou (Sec 2, Subject Report).

*Response: The watershed model was used to predict freshwater inflow to Patrick Bayou from the surrounding watershed.*

Comment C.2: Surface runoff to the bayou is determined using assigned hydrologic soil groups, land type designations and a range of precipitation events. The resulting discharge volumes are converted to flow rates in the bayou (Sec 2.2.1, Subject Report).

*Response: This comment is an accurate statement describing the function of the watershed model.*

Comment C.3: Average rainfall statistics for the Patrick Bayou watershed were determined from Harris County Homeland Security and Emergency Management (HCOEM) rainfall gauges in the vicinity of the watershed (Ziegler, 2009; Sec 2.2, Subject Report).

*Response: Rainfall data were obtained from the Harris County Homeland Security and Emergency Management (HCOEM). HCOEM maintains nearly 900 gauges throughout Harris County that measure climate conditions. Four gauges were identified near the study area with rainfall data available during the model calibration period (Figure 2-3). The identification numbers for these four gauges are: 2230 (Toll Road East); 240 (B100 Armand Bayou at Beltway 8); 270 (B112 Willow Spring at Fairmont Parkway); and 640 (F216 Little Cedar Bayou at Sens Road). During initial development and testing of the watershed model, it was determined that averaging rainfall measured at the four stations (i.e., arithmetic average) provided the best estimate of precipitation in the watershed. The precipitation gauges also recorded rainfall on a sub-hourly basis with an inconsistent period between measurements. Therefore, the data were converted to hourly rainfall values for input to the watershed model. The volume of rainfall that flowed through each sub-basin was a function of the average rainfall from the four stations multiplied by the area of each sub-basin.*

Comment C.4: The watershed drains to Patrick Bayou via inflow from surface runoff and two (2) inflow channels: 1) the City of Deer Park main inflow and 2) the East Fork inflow (Shell, 2000; Shell, 2002; Ziegler, 2009; Sec 2.3, Subject Report). The base-flows of both channels were measured during periods of no rainfall.

*Response: This comment is an accurate statement*

Comment C.5: Calibration of the watershed model was performed in October 2006 using measured and model-predicted water surface elevations and current velocities in the channels of the Main inflow and East Fork inflow (Sec 2.3.4, Subject Report). A transient calibration of the watershed model was accomplished using precipitation events during October 2006. The most intense rainfall event that occurred during the calibration period had a 10-year return period (Ziegler, 2009; Sec 2.2, Subject Report).

*Response: The watershed model does not predict water surface elevation and current velocities in the channels of the Main and East Fork inflows. This model does predict flow rates in those two channels, and the predicted and measured flow rates during October 2006 were compared during the calibration process.*

## Section D: Patrick Bayou Hydrodynamic Module

Comment D.1: The hydrodynamic model uses time-variable water discharge values to the bayou generated by the bayou watershed model (Section C) and a three-dimensional numerical grid of the Patrick Bayou bathymetry to predict current velocities, water depths and bed shear stresses for simulations of a range of flow regimes and conditions in the bayou (Sec 2.3, Subject Report). The model Environmental Fluid Dynamics Code (EFDC-Hydro), developed for the U.S. EPA (USEPA, 2002) was used to calculate the hydrodynamic data. Data generated by EFDC-Hydro were used as input for the Patrick Bayou sediment transport model.

*Response: This comment is an accurate statement*

Comment D.2: EFDC-Hydro calculates finite difference solutions to numerous hydrodynamic equations coupled to the three-dimensional grid representing Patrick Bayou (Item D.1) through time (USEPA, 2002).

*Response: This comment is an accurate statement*

Comment D.3: The boundary conditions for the EFDC-Hydro Patrick Bayou simulations included known water surface elevations at the edges of the model domain, current velocities, salinity, the October, 2006 data used to calibrate the watershed model (Item C.5), local tidal fluctuation data, etc. (Sec 2.3.3, Subject Report).

*<u>Response</u>: Time variable tidal elevations and salinity values were specified at the two model boundaries in the HSC. Time variable flow rates of freshwater, based on watershed model predictions, were specified at the two inflow boundaries on the Main channel and East Fork.*

<u>Comment D.4</u>: Transient calibration of the EFDC-Hydro model as performed using two parameters: water surface elevations and current velocities measured in the bayou (Sec 2.3.4). The model calibration comprised the comparison of the measured parameter data against the model-predicted data for a 14-year period (1993-2006).

*<u>Response</u>: The hydrodynamic model was calibrated using water surface elevation and current velocity data collected during October 2006. The sediment transport model was calibrated over a 14-year period (1993-2006).*

## Section E: Patrick Bayou Sediment Transport Model

<u>Comment E.1</u>: The sediment transport model uses water depth, current velocities and other hydrodynamic data generated by the hydrodynamic model (Section D) to simulate:
1) transport of sediment via suspended load and bed load, 2) erosion of sediment from the bed, 3) deposition of sediment to the bed and 4) sediment composition of the bed. The simulations are three dimensional and through time (Sec 2.4.1, Subject Report).

*<u>Response</u>: Bed load transport was not simulated by the sediment transport model because the morphology and bed composition (i.e., primarily cohesive) of Patrick Bayou indicate that minimal bed-load transport occurs in the bayou.*

<u>Comment E.2</u>: The model SEDZLJ (e.g., Sandia, 2005) was used to simulate the dynamic transport processes of sediment in Patrick Bayou.

*<u>Response</u>: This comment is an accurate statement*

<u>Comment E.3</u>: SEDZLJ was used to simulate the transport processes of only cohesive sediments, since Patrick Bayou is considered to be effectively devoid of non-cohesive sediment (Table 2-3). A consequence of this model assumption is that bed load processes also were not simulated. See F.3.

*Response: The sediment bed was assumed to be a cohesive bed because sediment samples collected in the bayou are primarily composed of cohesive sediment, with isolated, localized areas of non-cohesive sediment also being present. A cohesive bed is composed of a mixture of clay, silt, sand and gravel.*

Comment E.4: The erosion rates of the cohesive sediment bed at depth were determined at twelve (12) core locations in the bayou using SEDflume analysis (e.g., McNeil et al., 1996; Jepsen et al., 2004; Borrowman et al., 2006).

*Response: This comment is an accurate statement.*

Comment E.5: The spatial distribution of erosion rates (Item E.4) throughout the bayou could not be interpolated for the purpose of assigning separate values to grid cells in the model domain (Sec 2.4.3, Subject Report). Instead, certain bayou sediment bed erodibility parameters were assumed to be spatially constant for each of the horizontal depth layers (Table 2-6, Subject Report).

*Response: This comment is an accurate statement*

## Section F: Calibration of the Patrick Bayou Sediment Transport Model

Comment F.1: Calibration of the sediment transport model was performed over two (2) time scales: 1) short term and 2) long term (Sec 2.4.5, Subject Report).

*Response: This comment is an accurate statement: 1) high-flow events during October 2006; and 2) 14-year period (1993-2006).*

Comment F.2: Calibration of the short-term timescale was based on suspended solids concentrations and inflows measured during October 2006 (Sec 2.4.5, Subject Report) which included a 10-year return high flow event (Item C.5).

*Response: This comment is an accurate statement*

Comment F.3: The long-term calibration was performed using data from the period 1993 through 2006 and is coincident with the calibration period for EFDC-Hydro (D.4). Calibration parameters of long-term sedimentation in the bayou were derived from annualized suspended sediment loads from sampling stations in the HSC upstream and downstream of the Patrick Bayou confluence (Sec 2.4.4). A Patrick Bayou suspended sediment concentration was determined from those data. The assumed composition of the sediment was 100% class 1 (clay/silt) (see E.3).

*Response: The calibration target for the 14-year simulation was net sedimentation rates at six locations in Patrick Bayou. The data-based net sedimentation rate values were determined from an analysis of $^{210}$Pb data obtained from radioisotope cores collected at those locations. The composition of the incoming sediment load was assumed to be 100% class 1 (clay/silt) during low-flow conditions, with a mixture of clay/silt and sand being included in the incoming sediment load during high-flow conditions.*

Comment F.4: The long-term sediment transport calibration was determined to have under-predicted the NSR in the bayou (Sec 2.4.5). The discrepancy in the NSR during calibration was attributed to: 1) unknowable variability of suspended sediment and 2) bayou base-flow (Sec. 2.4.5).

*Response: A complete description of the calibration process, with new results, is provided in the revised version of the report.*

## Section G: Calibration of Patrick Bayou Sediment Transport Model – Bayou Base-Flow and In-Flows

Comment G.1: Long-term (14 year) bayou base-flow values used in the sediment transport model (Sec F) are based on in-flow measurements made in October 2006 (Item's C.4, C.5 and F.2).

*Response: Base-flow discharge was estimated using flow rate data collected at stations PB075 and EF005 during October through December, 2006. Only data collected during the days of no precipitation were used in the base-flow analysis. Furthermore, flow rate data collected within a 48-hour period following a rainfall were excluded. Cumulative frequency distributions of base-flow data collected during the 2006 field study at stations PB075 and EF005 are presented on Figure 2-9. For station PB075 (i.e., Main inflow), base-flow discharge ranges from about 1 to 100 cubic feet per second (cfs), with an average value of 28* *cfs. For station EF005 (i.e., East Fork), base-flow discharge is about a factor-of-ten less than the Main inflow, with an average value of 2 cfs and a range of about 0.1 to 10 cfs.*

Comment G.2: The average total freshwater inflow during the 14-year period ending in 2006 is 40 ft3/s (Sec 2.3.3, Subject Report), or approximately 25.9 MGD, 85% of which discharges through the Main inflow.

*Response: The average total freshwater inflow from the watershed (i.e., excluding inflow from the OxyChem outfalls) for this 14-year period is 40 cfs, with discharge from the Main inflow, East Fork, and direct runoff contributing 85%, 8%, and 7%, respectively, to the total inflow from the watershed.*

Comment G.3: Actual total in-flow to the bayou during most of the 14-year calibration period was significantly higher. Additional discharges to the bayou occurred as production outfalls from numerous facilities around the bayou. Most significant of these are the OxyVinyls outfalls (NPDES # TX0007412). Average total discharge to Patrick Bayou for OxyVinyls was gauged to be 69.2 MGD during the period from January 1998 to October 2006 (data were not available for the period 1993 – 1997). This discharge is more than 2.5 times the combined in-flows from the Main and the East Fork channels (e.g., Shell 2007a). Appendix A contains a summary of average discharges to the bayou during most of the 14-year period of calibration.

*Response: The inflows from the three OxyChem outfalls have been incorporated into the hydrodynamic and sediment transport models. The comparison of inflows from the watershed (e.g., Main channel and East Fork) and OxyChem outfalls discussed in the comment focus on long-term average values. It must be remembered that even though the long-term average inflow from the watershed is only 40 cfs, much higher inflow rates (e.g., 5,000 cfs or higher) occur during storm events.*

Comment G.4: The discharges from the OxyVinyl outfalls represent the largest in-flows to the bayou (G.3) during the 14-yr calibration period. However, the in-flows are not accounted for in the sediment transport calibration (F.4).

*Response: The inflows from the three OxyChem outfalls have been incorporated into the hydrodynamic and sediment transport models. While the average inflow of the OxyChem outfalls is higher than the average inflow from the watershed, incoming flows from the Main* *channel and East Fork are significantly higher than OxyChem outfall dishcarge during storms.*

Comment G.5: OxyVinyl outfalls 001, 002 and 003 were located downstream of Sample PB048 and, upstream of Sample PB022 (Parsons, 2002; Fig 2-25, Ziegler, 2009). Therefore, the OxyVinyl outfalls discharged on the eastern bank of the bayou approximately halfway between the location of the Main in-flow and sample location PB022 (Fig 2-27, Subject Report).

*Response: The OxyChem outfalls are located downstream of station PB052 and upstream of station PB022, along the eastern bank of the bayou.*

Comment G.6: The TCEQ suggests that a reason that the long-term sediment transport model calibration under-predicted the bayou NSR (F.4) is, in part, related to omitting the majority of actual in-flows to the mid-bayou during most of the calibration period (G.3, G.4)

*Response: The inflow from the three OxyChem outfalls has been incorporated into the hydrodynamic and sediment transport models. The effects of inflow and sediment loads from the OxyChem outfalls on sediment transport processes in the bayou have been incorporated into the model predictions.*

## Section H: Patrick Bayou Sediment Transport Model Calibration – 210Pb Isotopy

Comment H.1: The bayou net sedimentation rates were under-predicted during the sediment transport model calibration (Sec G, *Item G.6*). Therefore, a 210Pb "age-dating analysis" was performed for the purpose of determining actual sedimentation rates (Sec 2.4.5, Subject Report; Ziegler et al., 2009).

*Response: The age-dating analysis was not conducted due to results of the sediment transport model calibration. Net sedimentation rates were estimated at six locations in Patrick Bayou based on the results of the age-dating analysis. These data-based values were used as calibration targets for the model.*

Comment H.2: The use of short-lived geochronometers for recent sedimentation is based on measurements of excess, or "unsupported" Pb activity compared to the background, or "supported" Pb activity. The unsupported Pb is associated with recently transported sediment. Together with the known 210Pb decay constant and the thickness of the "unsupported" sediment layer an age can be determined for that sediment. If a time datum is established, a "date" for the sediment can be determined (e.g., USGS, 2004; Jeter, 2000; USGS, 1998).

*Response: Lead-210, which is a decay product of volatilized atmospheric radon-222 ($^{222}Rn$), is present in sediments primarily as a result of recent atmospheric deposition. Radon-222 is a volatile, short-lived, intermediate daughter of uranium-238 ($^{238}U$), a naturally occurring radioisotope found in the earth's crust. The $^{210}Pb$ activity in a sediment sample represents the total $^{210}Pb$ activity, which is measured indirectly by analysis of its radioactive decay products bismuth-210 or polonium-210. Total $^{210}Pb$ activity consists of two components:*

- *Unsupported $^{210}Pb$, which represents $^{210}Pb$ that is deposited on the earth's surface at an approximately constant rate via atmospheric deposition.*
- *Supported $^{210}Pb$, which is the background $^{210}Pb$ activity in the sediment. In aquatic environments, the approximately constant atmospheric flux of $^{210}Pb$ and its decay half-life of 22.3 years results in relatively homogeneous $^{210}Pb$ activities within the biologically-active surface layer of the sediments and activities that decay exponentially below this depth. For this reason, $^{210}Pb$ serves as a useful tracer for estimating net sedimentation rates and mixing depths in aquatic systems.*

Comment H.3: Ten (10) sediment core samples were taken along the length of Patrick Bayou and analyzed for 210Pb activity at five (5) different depths (Table 1, Ziegler et al., 2009). An additional five (5) sediment core samples along the length of Patrick Bayou were analyzed for 210Pb activity (Fig 2-25, Subject Report). *Only two (2) locations from this combined sample suite were used for the long-term sediment transport model calibration*: core samples PB022 and PB048.

*Response: The age-dating analysis produced estimates of net sedimentation rate at six locations: PB006, PB016, PB022, PB025, PB048 and PB052. Net sedimentation rates could not be estimated based on the radioisotope data collected at the other four core locations (i.e., the cores were not "readable").*

Comment H.4: Since no time datum could be determined in Patrick Bayou, only a sedimentation rate was determined (based on thickness of sediment with unsupported 210Pb activity using the method in Jeter [2000]).The net sedimentation rates determined are: PB022 – 0.82 cm/yr and PB048 – 1.6 cm/yr (Table 2-7, Subject Report).

*Response: The age-dating analysis produced estimates of net sedimentation rate at six locations: PB006 (0.3 cm/yr), PB016 (0.15 cm/yr), PB022 (0.82 cm/yr), PB025 (0.25 cm/yr), PB048 (1.7 cm/yr) and PB052 (2.5 cm/yr).*

Comment H.5: ("Table 2-5" pg 39, Subject Report, should read "Table 2-7") ("Equation 2-16" pg 53, Subject Report, should read "Equation 2-13").

*Response: The text has been modified.*

Comment H.6: Results of 210Pb isotopy from the other three (3) sediment core samples (Item H.3) were "unreadable" because of high variability (Sec 2.4.5, Subject Report). Results of 210Pb activity of the remaining ten (10) cores in Ziegler et al. (2009) were not used in the sediment transport model calibration. However, that report notes that deposition-erosion cycles can make the results "unreliable" for determinations of net sedimentation rates (Ziegler, et al., 2009).

*Response: The age-dating analysis produced estimates of net sedimentation rate at six locations: PB006 (0.3 cm/yr), PB016 (0.15 cm/yr), PB022 (0.82 cm/yr), PB025 (0.25 cm/yr), PB048 (1.7 cm/yr) and PB052 (2.5 cm/yr).*

Comment H.7: Estimated net sedimentation rates from Ziegler et al. (2009) show a range from 0.15 cm/yr to2.5 cm/yr (Table 1, Ziegler et al., 2009).

*Response: This comment is an accurate statement (i.e., net sedimentation rates estimated from the geochronology analysis of the radioisotope cores range from 0.15 to 2.5 cm/yr)*

Comment H.8: The Pb-210 method for sediment age dating and sedimentation rate determinations is best suited to quiescent subaqueous settings such as bays, marshes, lakes, etc. (Jeter 2000). However, the predicted magnitude of erosion activity in Patrick Bayou (Sec E & J) apparently demonstrates that areas of the bayou may be too dynamic and not ideally suited for the application of the method. This is evidenced by the paucity of Pb-210 data that could be used and the high magnitude of variability in the results (H.3, H.6).

*Response: The use of $^{210}$Pb activity data for estimating net sedimentation rates is, and has been, successfully used in a wide-range of aquatic systems, including rivers, bays and estuaries, including: Lower Duwamish Waterway (estuary near Seattle); Upper Hudson River (freshwater river); Lower Hudson River and New York Harbor (estuarine system); and Passaic River and Newark Bay (estuarine system in New Jersey) This type of analysis was applied to radioisotope cores collected from Patrick Bayou and produced reliable estimates of net sedimentation rate at six locations.*

Comment H.9: The high variability of Pb-210 data (H.3, H.6, H.8) is an indication that erodibility in Patrick Bayou is not spatially constant. However, erodibility constants obtained from Sedflume analyses and used in SEDZLJ simulations are assumed to be spatially constant for each horizontal model layer (E.4, E.5). This procedure decreases the confidence in the resulting predictions of erosion/sediment rates at any given location in the bayou.

*Response: There is no demonstrated relationship between vertical profiles of $^{210}$Pb activity and sediment erosion properties. The Sedflume data indicate that horizontal and vertical variability exists in the erodibility of Patrick Bayou sediment. However, assuming that the erosion properties of Patrick Bayou sediment are constant in the horizontal plane is a valid approximation, which has been successfully used during modeling studies at other sites. The effect of this assumption on model predictions was evaluated during a model sensitivity analysis.*

Comment H.10: The long-term net sedimentation rate at the bayou sample location PB048 was determined to be approximately two times that of sample location PB022 (H.4). Since the OxyVinyl outfalls occurred downstream of PB048 and upstream of PB022 (G.3, G.4, G.5), the discrepancy between the NSRs of the two sample locations may be the result of significantly contrasting current velocities, scouring, shear stresses and sediment class to which sample location PB022 was subjected during the time period recorded in the sample vis-à-vis sample location PB048.

*Response: The data indicated that there is a factor-of-two difference between NSR values at PB022 (0.82 cm/yr) and PB048 (1.6 cm/yr). This difference in measured NSR is attributable to differences in the erosion/deposition environment at these two locations, including potential effects of sediment loading from the outfalls. This difference in NSR values between the two locations is not related to the model.*

## Section I: Patrick Bayou Groundwater Hydrogeology

*<u>General response to comments related to groundwater:</u>*

*The groundwater system surrounding the Site has been extensively studied under the direction and supervision of the Texas Commission on Environmental Quality (TCEQ) at each of the three Patrick Bayou Joint Defense Group (JDG) member facilities (Shell, OxyVinyls, and Lubrizol). There are no existing data that indicates existing groundwater from any of these facilities have a significant effect on surface-layer bed concentrations in Patrick Bayou.*

*Shell and OxyVinyls, L.P. (OxyVinyls) Deer Park Facilities have completed their on-Site investigations with TCEQ under the Texas Risk Reduction Program, and Lubrizol is in the process of completing their groundwater evaluations. The Patrick Bayou JDG intends to provide a comprehensive groundwater source evaluation based on the reports and data generated from each facility upon the completion of Lubrizol's work with TCEQ. If any future data indicates groundwater may provide a potential ongoing source of contaminants to Patrick Bayou, those pathways will be fully evaluated at that time.*

<u>Comment I.1</u>: The hydrostratigraphy that underlies Patrick Bayou has been established via correlations of numerous soil borings logs, cores and monitoring well construction logs throughout the bayou (e.g., Shell, 2006b).

*<u>Response</u>: We agree, similar investigations to those cited in the Shell 2006b reference exist for the OxyVinyls and Lubrizol facilities .*

<u>Comment I.2</u>: Three (3) groundwater-bearing hydrostratigraphic units have been identified beneath the bayou (e.g., Shell, 2006b; Shell, 2003).

*<u>Response</u>: We agree, there is corroborating evidence for these same hydrostratigraphic units in groundwater evaluations at the Lubrizol and OxyVinyls facilities.*

<u>Comment I.3</u>: Static water level in the shallow-most ground-bearing hydrostratigraphic unit in the Shell Deer Park facility (to the west) is higher than the mean surface water level in Patrick Bayou and the gradient is towards Patrick Bayou (e.g., Shell, 2006b).

*<u>Response</u>: This comment is an accurate statement..*

<u>Comment I.4</u>: Groundwater influx to Patrick Bayou from the Shell Deer Park side (only) was calculated for all hydrostratigraphic units from over 100 discretized segments along the Shell/Deer Park-Patrick Bayou shoreline interface (Shell, 2006a, Shell 2006c). The results of the calculations indicate that up to 3.3x104 gallons/day of groundwater enter the bayou from the west. Since hydrogeologic conditions are similar on the east flank of the bayou, the TCEQ presumes that an additional groundwater influx of undetermined volume enters the bayou from hydrostratigraphy to the east.

*<u>Response</u>: This amount of groundwater flow (i.e., 33,000 gallons/day) corresponds to a a flow rate of 0.05 cfs, which is about 0.1% of the average freshwater inflow from the watershed (i.e., 40 cfs). Thus, groundwater inflow is negligible with respect to freshwater inflow from the watershed and has an inconsequential effect on hydrodynamics and sediment transport in Patrick Bayou.*

<u>Comment I.5</u>: The distribution of groundwater flux from the west to Patrick Bayou is not uniform. The area of highest groundwater flux is in the vicinity of sample location PB022 (Shell, 2006a; Items H.3, H.4 and H.10). (The TCEQ offers no conjecture on the possible effects that increased sediment pore pressure [from groundwater flow] has on erodibility of the sediment bed.)

*<u>Response</u>: Groundwater flux into Patrick Bayou has a negligible effect on sediment transport processes in the bayou.*

<u>Comment I.6</u>: Shallow groundwater at the Shell-Deer Park facility has been determined to be affected (e.g., Shell, 2003). On-going assessments are being performed for the purpose of determining the nature of and the degree to which the influx of affected groundwater (Item I.4), as underflow to Patrick Bayou, may have impacted, and may continue to impact the sediment bed.

*<u>Response</u>:*
*Beginning in November 2005, Shell and the TCEQ cooperatively worked through the technical issues related to a Patrick Bayou Weight-of-Evidence (WOE) evaluation in a series of work group meetings. These included the following three work groups to develop and evaluate specific lines of evidence (LOEs) for the WOE evaluation:*

- *Chemical Correspondence Analysis (CCA) Work Group*
- *Chemical Mass Loading (CML) Work Group*
- *Spatial Analysis of Toxicity (SAT) Work Group*

*Additionally, a Site Conceptual Model (SCM) Work Group was formed to support the three LOE work groups by developing a mutually agreeable conceptual model that describes the interaction of the Site groundwater with the surface water and sediments in Patrick Bayou. The CML Work Group concluded the following:*

  - *Groundwater could not contribute sufficient loading to Patrick Bayou to account for any significant portion of the mass of COCs observed in the sediments; and,*
  - *In most cases, groundwater underlying the Site could not account for even 1% of the observed chemical mass in Patrick Bayou sediment.*

*Based on the review a review of the different lines of evidence investigated by Shell and the TCEQ, the Steering Committee for the Patrick Bayou WOE evaluation determined that the results of their analyses support the conclusion that COCs in Site groundwater do not appear to cause or contribute to sediment toxicity in Patrick Bayou.*

*On April 30, 2009, the Steering Committee for the Patrick Bayou WOE evaluation, which is composed of Shell and TCEQ stakeholders, concluded that the WOE evaluation had been completed and its goals had been met. Based upon the findings of the three LOE work groups described above, the Steering Committee determined that the evidence showing that groundwater underlying the Site does not cause Patrick Bayou sediment toxicity.*

*Reference: Shell Deer Park, Deer Park, Texas, July 2009. Groundwater Evaluation Shell Deer Park Facility and Patrick Bayou Superfund Site, Deer Park, Texas.*

<u>Comment I.7</u>: In the case where contaminated groundwater creates a continuing impact to bayou surface sediments (I.6) through which it passes and to which it partitions contaminants, the physical (fate) model is one of a continuing source of contaminated sediment in the system. The consequences of such a process can include:

- A continuing external sediment source will be mobilized and re-deposited in the system, thereby adding contaminant mass to the area at which it's been deposited and
- Contaminated groundwater moving through bayou surface sediments in the areas of net deposition could continue to partition contaminant mass to re-deposited (clean) sediments and resulting in increased concentrations.

*Response:*

*As stated above, the groundwater system surrounding the Site has been extensively studied under the direction and supervision of the Texas Commission on Environmental Quality (TCEQ) at each of the three Patrick Bayou Joint Defense Group (JDG) member facilities (Shell, OxyVinyls, and Lubrizol). There are no existing data that indicates existing groundwater from any of these facilities have a significant effect on surface-layer bed concentrations in Patrick Bayou.*

*Shell and OxyVinyls, L.P. (OxyVinyls) Deer Park Facilities have completed their on-Site investigations with TCEQ, and Lubrizol is in the process of completing their groundwater evaluations. The Patrick Bayou JDG intends to provide a comprehensive groundwater source evaluation report, based on the reports and data generated from each facility upon the completion of Lubrizol's work with TCEQ. If any data indicates groundwater may provide a potential ongoing source of contaminants to Patrick Bayou, those pathways and their affect on sediment and/or surface water quality in Patrick bayou will be fully evaluated at that time as part of the RI/FS process.*

## Section J: Patrick Bayou Mixing Zone Mechanics and Implications for Attenuation

Comment J.1: A physical model is presented for the attenuation of contaminants in the surface sediment layer (Ziegler, 2009; Sec 3, Appendices A and B, Subject Report). This is the aspect of the modeling that is used to predict attenuation rates at different locations in the bayou.

*Response: The sediment transport model was used to evaluate the rate of natural attenuation in surface-layer sediment due to mixing of sediment from external sources with bed sediments. Chemical fate and transport processes affecting natural attenuation in the bayou were not simulated.*

Comment J.2: The multi-layer cohesive sediment bed model simulated with the SEDZLJ transport module demonstrates the complex interaction of the sediment budget that occurs amongst the five (5) modeled layers subjected to different surface water flow (shear stress) regimes (e.g., Appendices A and B, Subject Report; Slides 32 to 41, Ziegler, 2009).

*Response: This comment is an accurate statement.*

Comment J.3: The sediment interaction scenarios predicted by SEDZLJ for various ranges of shear stress on the bed (Item J.2) are too numerous to detail here. However, it is these modeled interactions upon which attenuation half-lives are based (Sec 3.3.1, Subject Report).

*Response: This comment is an accurate statement*

Comment J.4: The numerical model scenario upon which the sediment attenuation half-lives are based (Item J.3) is as follows: 1) at t=0 (1993) the sediment bed is comprised uniformly of the parent-bed source composition (Sec 3.3, Subject Report); 2) an active surface layer of cohesive Class 1 sediment forms with the advent of critical shear stress (current velocity) in which sediment transport is initiated both into and out from the active layer; 3) simultaneously, a "buffer" forms at a depth determined by the magnitude of shear stress in which takes place sediment exchange between the active layer and the parent-bed source; 4) as sediment exchange between suspended sediment and parent-bed source in the active layer continues, the parent bed source concentration decreases; 5) the rate at which the parent-source concentration in the active layer decreases by exchange is the metric by which the attenuation half-life is determined.

*Response: The sediment transport model tracks the relative amounts of sediment from two sources (i.e., original bed and external loads) in a surface layer of the bed, which is specified to be 10 cm thick. At the beginning of the 14-year simulation, the 10-cm layer is composed entirely of original bed sediment. The rate at which the original bed material in the 10-cm layer decreases is used to calculate the half-life of natural attenuation in this surface layer.*

Comment J.5: The attenuation half-life values are model determinations based on the net dilution of cohesive parent-bed source material in an active mixing layer with an external sediment load during a time period (Item J.4; Sec 3.2, Subject Report).

*Response: This comment is an accurate statement*

Comment J.6: The attenuation half-live values (J.4, J.5) cannot be interpreted as the attenuation rates of a contaminant in the same sediment mixing zone. For example, if the contaminant concentration of the external sediment source was exchanging with parent-bed source sediment with same contaminant concentration, no attenuation of contaminant in the sediment bed would occur.

*Response: The attenuation half-live values can be interpreted as the attenuation rates of chemical concentrations in the mixing-zone layer due to deposition of sediment from upstream sources which are "clean" (i.e., zero chemical concentration on particles from this source). This attenuation rate is the maximum value that can be achieved for a natural recovery scenario (i.e., no active remediation) with all external sources controlled. To the extent that sediment from upstream sources are contaminated with chemicals, then the attenuation rate will decrease and natural recovery times will increase. For the situation where chemical concentrations on upstream source sediment are equal to bed concentration, then no attenuation will occur, as noted in the comment. While some data are available for chemical concentrations on upstream sediments, additional data collection is envisioned to improve the characterization of those sediments. These data can be used to refine the predicted rate of attenuation in the future. However, the present analysis is useful for developing a basic understanding of natural recovery in the bayou.*

Comment J.7: The TCEQ assumes that the model cohesive external source suspended sediment composition is constant per the annualized suspended sediment load described in F.3.

*Response: The composition of the incoming sediment load to the bayou varies with flow rate. See response to F.3.*

Comment J.8: Since no modeling of sediment/contaminant fate was performed (J.5, J.6), the magnitude of contaminant attenuation in the Patrick Bayou sediment bed surface cannot be determined.

*Response: Even though chemical fate and transport was not explicitly simulated in Patrick Bayou, the results of the sediment transport model can be used to estimate the rate of attenuation of chemical concentrations in the surface layer of the bed.*

## Section K: Patrick Bayou Sediment Fate during Natural Recovery

Comment K.1: Natural recovery is a remedial action by which the environmental risk of contaminated surface water sediment is effectively reduced by a process of progressive burial and sequestration by uncontaminated sediments (e.g., USEPA, 2008; USEPA, 2005; Brenner et al., 2002).

*Response: This comment is an accurate statement and monitored natural recovery will be evaluated during the FS.*

Comment K.2: The subject report is being used to "… *examine the importance of sediment transport process relative to potential remedial alternatives for the bayou* …" (Sec 1, Subject Report). The results of the subject study are intended to be used to evaluate the potential efficacy of natural recovery in the forthcoming *Feasibility Study*.

*Response: The sediment transport model will be used to evaluate the effectiveness of a range of remedial alternatives, which will include the evaluation of natural recovery.*

Comment K.3: The natural recovery remedial action is effective where sedimentation is net depositional (e.g., Brenner et al. 2002, 2004). The USEPA indicates that net depositional environments suited to the application of natural recovery "… require relatively slow surface velocities … [occurring] … in deltas, lakes and slow-moving portions of rivers …" (JEE 2001).

*Response: Net depositional areas can occur in a wide range of hydrodynamic environments and natural recovery is not limited to the types of systems discussed in JEE (2001).*

Comment K.4: Based on the watershed model analysis performed in the report, Patrick Bayou initially does not appear to meet the qualifications (K.3) of a viable candidate for natural recovery. The TCEQ recommends that aspects of the forthcoming FS address this issue.

*Response: Simplified physical characterization of the hydrology and hydrodynamics of the bayou is not a scientifically valid approach for evaluating the potential efficacy of a remedial alternative. The use of the modeling framework described in the report provides a scientifically valid approach for evaluating the efficacy of natural recovery, along with other remedial alternatives. In addition, predictions of the sediment transport model provide only one line of evidence in a weight-of-evidence approach for evaluating the effectiveness of various remedial alternatives in Patrick Bayou.*

Comment K.5: The subject report defines areas in Patrick Bayou that modeling indicates undergoes net erosion and net deposition (Sec 3). However, these locations are not shown in relation to areas of contaminated sediments. Therefore, it remains possible that areas of the bayou within the model domain that been identified as undergoing net erosion (Fig 3-4) could contain contaminated sediments that may be re-mobilized and re-deposited at a location that would result in increasing sediment contamination, or that are otherwise not subject to net deposition.

*Response: The net erosion areas shown on Figs 3-4 to 3-6 represent what occurs during a specific high-flow event. Note that for long-term, multi-year periods (i.e., 14-yr simulation), net erosion only occurs in a small area of the bayou. Nearly all of the areas that are net erosional during a high-flow event are net depositional over long-term periods. The combined effects of erosion and deposition over multi-year periods (i.e., remobilization and re-deposition) are incorporated into the model results. Even though chemical fate and transport will not be simulated, the modeling framework will be used during the FS as one line of evidence during the evaluation of various remedial alternatives.*